Effect of Phosphate Fertilizers on Growth and Manganese Uptake of Rubber Seedlings

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Abstract— Since **the concentrations of manganese (Mn) in soils and leaves in most rubber plantations in Thailand are higher than optimum level. To reduce Mn uptake becomes necessary. It is well known that application of phosphate (P) fertilizer is able to reduce Mn toxicity symptoms in some plants and also solve the P deficiency in acid soil. This experiment aimed to investigate the effect of P fertilizers on growth and Mn uptake in rubber. The rubber seedlings (RRIM 600) were grown in a greenhouse using completely randomized block design with 5 treatments and 5 replicates. The 5 treatments consisted of without P fertilizer (control) and 40 mg kg-1 P2O5 in the forms of diammonium phosphate (DAP), triple super phosphate (TSP), rock phosphate (RP) (as avai. P) and RP (as total P). The result showed that addition of P fertilizer increased plant growth in terms of stem diameter, leaf number, trunk height and dry weight. Both of the RP treatments gave the highest growth followed by TSP and DAP. Moreover, adding P fertilizers decreased Mn concentrations in leaf, petiole, stem, tap root and lateral root compared with the control. This finding proves that P fertilizers play an important role in rubber gown in acid soils containing low P and high Mn and reduce Mn uptake.**

Keywords— Manganese toxicity, phosphate fertilizer, rubber

I. INTRODUCTION

Manganese toxicity occurs in crops grown in acid soils and normally liming will be ready to correct this problem by increasing pH. But liming has some limitation, such as the adversity and inefficient of plow layer liming which do not readily penetrate to the deeper soil zones [13] and the imbalances of several nutrient in soil [8]. However some researchers found an antagonistic interaction between P and Mn toxicity symptoms. The experiment on cotton [32] and potato [6] described that P had significant beneficial effect to control the reducing Mn toxicity symptoms. The experiment in pokeweed implied that Mn immobilization and detoxification were contributed by addition of P [4]. However, some researchers also found the synergism interaction between P and Mn, such as in potato which grown in hydroponic [38], potato in micro culture techniques [22] and tomato [27]. Meanwhile, there are limited studies in rubber seedling.

In acid soil, P fixation is one of the main problem which reduces P availability for plant growth [11].The deciding to use P fertilizer for solving those problems will be so effective. Moreover, it will reduce Mn toxicity, in other hand it can increase P availability in acid soils. Some types of phosphate fertilizers are ready to apply and commonly use in rubber plantation are diammonium phosphate ($(NH_4)_2HPO_4$; DAP), triple superphosphate ($Ca(H_2PO_4)_2$; TSP) and rock phosphate ($[(Ca_3(PO_4)_2]_3 \bullet CaF_x$; RP) [17].

Rock phosphates are commonly used in rubber plantations as the soil is acidic. The slow availability of RP is beneficial because the opportunity of P fixation can be reduced by this water insoluble phosphates utilization [33]. The usage of TSP and DAP are for direct application as starter fertilizers because both of them are completely water soluble [17]. The objective of this study was to investigate the effect of phosphate fertilizers on manganese uptake and growth of rubber seedlings.

II. MATERIAL AND METHOD

Surface (0-30cm) soil of Kho Hong soil series (Kh) (Coarse-loamy, kaolinitic, isohyperthermic Typic Kandiudults) in Khlong Hoi Kong District was collected for this study. Rubber seedlings (RRIM 600) were grown in the plastic pot (15 kg soil/pot). In the beginning of all treatemts, for every kg soils were added 50 mg Mn ($MnSO_4$), 100 mg K_2O (KCl), 100 mg N (Urea) and 40 mg P_2O_5 as RP (as avai P), RP (as total P) TSP and DAP. The randomized complete block design (RCBD) with 5 treatments and 5 replications was adopted.

The trunk height, stem diameter and number of leaf were well documented. While at the end of experiment, dry weight of leaf, petiole, stem, tap root and lateral root were recorded. The fresh leaf was also collected for chlorophyll analysis [23], while the dry plant tissues were used for nutrients (N, P, K, Mn, Ca and Mg) analysis [20]. Avai.P, exch. K, Ca, Mg, extr.Mn, pH, EC and organic matter in soils also measured [19]. Then the data were subjected to analysis of variance (ANOVA).

III. RESULTS

The dry weights (DW) of rubber applied P fertilizer were higher than that in the control (Table 1). The addition of TSP showed markedly the highest total DW (37.57 g) and tap root DW (23.68 g) ($P \leq 0.05$) followed by the addition of RP as total P, RP as avai. P, DAP and control. The leaf, petiole, stem and lateral root DW were not significant, but increased during P fertilizer application. The treatment of RP as total P gave the highest value for leaf (6.10 g), petiole (1.50 g) and stem (10.42 g) DW, but lateral root DW (6.66 g) in the TSP treatment was the highest.

TABLE 1. EFFECT OF PHOSPHATES FERTILIZERS ON PLANT DRY WEIGHT (G).

Treatment	Dry Weight (g)					
	Leaf	Petiole	Stem	Tap root	Lateral root	Total
Control	3.93	0.88	2.53	20.99ab	4.05	25.99a
DAP	5.51	1.15	3.06	21.43ab	4.22	30.30a
TSP	5.34	1.14	3.7	23.68b	6.66	37.57b
RP (as avai.P)	4.92	1.05	2.59	17.47ab	6.54	32.12a
RP (as total P)	6.10	1.50	10.42	13.58a	4.13	35.64a
F-Test	NS	NS	NS	*	NS	*
C.V. (%)	39.07	47.40	87.12	21.35	44.94	30.79

Remark: *= Significant difference at $P \leq 0.05$; NS = Not significant at $P > 0.05$.
The letters (a-b) in each column shows significant difference at $P \leq 0.05$.

The height, diameter and leaf number of rubber were significantly increased with addition of P fertilizers (Table 2). The result showed that TSP had the highest diameter (2.29 mm) ($P \leq 0.05$) and RP had significantly the highest value of height (34.32 cm) and number of leaf (39.22). This result was consistent with the result of dry weight that TSP and RP had markedly effect on the greater growth of rubber seedlings.

TABLE 2. EFFECT OF PHOSPHATES FERTILIZERS ON DIAMETER (MM), HIGH (CM) AND NUMBER OF LEAF

Treatment	Plant Growth		
	Diameter (mm)	Height (cm)	Number of leaf
Control	1.05a	16.05a	27.41a
DAP 40 mg P_2O_5 kg^{-1}	1.23ab	21.20a	38.75b
TSP 40 mg P_2O_5 kg^{-1}	2.29b	18.59a	30.39a
RP 40 mg P_2O_5 kg^{-1} (as avai.P)	1.54ab	22.63a	29.01a
RP 40 mg P_2O_5 kg^{-1} (as total P)	2.05ab	34.32b	39.22b
F-Test	*	**	*
C.V. (%)	33.22	28.18	31.44

Remark: *, ** = Significant difference at $P \leq 0.05$ and ≤ 0.01 respectively.
The letters (a-b) in each column shows significant difference at $P \leq 0.05$.

TABLE 3. EFFECT OF PHOSPHATES FERTILIZERS ON CHLOROPHYLL.

Treatment	Total Chlorophyll (mg dm^{-2})
Control	3.35ab
DAP 40 mg P_2O_5 kg^{-1}	4.45b
TSP 40 mg P_2O_5 kg^{-1}	4.03b
RP 40 mg P_2O_5 kg^{-1} (as avai.P)	3.70ab
RP 40 mg P_2O_5 kg^{-1} (as total P)	2.31a
F-Test	**
C.V. (%)	18.84

Remark: ** = Significant difference at $P \leq 0.01$.
The letters (a-b) in each column shows significant difference at $P \leq 0.05$.

The total chlorophyll tended to increase with the addition of P fertilizers ($P \leq 0.01$). Applying DAP gave markedly the highest (4.45 mg dm^{-2}) and RP as total P showed the lowest (2.31 mg dm^{-2}) (Table 3).

The effects of DAP, TSP and RP fertilizers on nutrients concentration in leaf (Table 4), petiole (Table 5), stem (Table 6), tap root (Table 7) and lateral root (Table 8) were clearly observed. Diammonium phosphate increased the N concentration in leaf (35.58 g kg^{-1}), stem (18.82 g kg^{-1}), tap root (13.23 g kg^{-1}) and lateral root (29.58 g kg^{-1}) significantly. The results also showed that DAP gave significant effect on the rising Mg concentration in leaf (1.87 g kg^{-1}), petiole (0.81 g kg^{-1}) and stem (0.96 g kg^{-1}). Meanwhile, in tap (0.65 g kg^{-1}) and lateral roots (1.02 g kg^{-1}). TSP had significantly effect on the increasing Mg concentration.

TABLE 4. EFFECT OF PHOSPHATES FERTILIZERS ON LEAF NUTRIENTS.

Treatment	Leaf Nutrients					
	N	P	K	Ca	Mg	Mn
	g kg^{-1}					mg kg^{-1}
Control	30.26ab	1.09a	13.58	5.04	0.89a	1.85
DAP	35.58b	1.33ab	15.56	5.65	1.87b	1.28
TSP	24.58a	2.20bc	14.91	4.94	1.49ab	2.46
RP (as avai.P)	33.50b	1.39ab	15.75	5.26	1.79b	1.29
RP (as total P)	29.09ab	2.55c	16.92	6.17	1.70ab	1.47
F-test	**	**	NS	NS	*	NS
CV	11.08	27.89	21.49	32.57	23.29	52.41

Remark: *, ** = Significant difference at $P \leq 0.05$ and ≤ 0.01 respectively.
NS = Not significant at $P > 0.05$.
The letters (a-c) in each column shows significant difference at $P \leq 0.05$.

TABLE 5. EFFECT OF PHOSPHATES FERTILIZERS ON PETIOLE NUTRIENTS.

Treatment	Petiole Nutrients					
	N	P	K	Ca	Mg	Mn
	g kg^{-1}					mg kg^{-1}
Control	12.23	0.53a	16.32a	3.40	0.62	2.59ab
DAP	20.39	0.73a	18.48ab	4.44	0.81	1.90ab
TSP	12.55	1.46b	18.20ab	3.40	0.56	2.91b
RP (as avai.P)	12.52	0.59a	19.99ab	4.98	0.67	2.14ab
RP (as total P)	12.42	2.61b	24.59b	5.51	0.72	1.34a
F-Test	NS	**	*	NS	NS	*
C.V. (%)	35.60	57.47	18.70	27.72	32.75	31.10

Remark: *, ** = Significant difference at $P \leq 0.05$ and ≤ 0.01 respectively.
NS = Not significant at $P > 0.05$.
The letters (a-b) in each column shows significant difference at $P \leq 0.05$.

Applying RP as total had the greatest responsible on the rising P concentration in leaf (2.55 g kg^{-1}), petiole (2.61 g kg^{-1}), stem (2.49 g kg^{-1}) and lateral root (1.35 g kg^{-1}) significantly ($P \leq 0.01$). Rock phosphate also gave the beneficial effect on the higher K concentration in every part of plant, significantly in the petiole (24.59 g kg^{-1}) (Table 5). In other hand, both of tap root (Table 7) and lateral root (Table 8) were also markedly found the highest Ca in the RP as total treatment.

TABLE 6. EFFECT OF PHOSPHATES FERTILIZERS ON STEM NUTRIENTS.

Treatment	Stem Nutrients					
	N	P	K	Ca	Mg	Mn
	$g\ kg^{-1}$					$mg\ kg^{-1}$
Control	6.62a	0.30a	13.11	3.05	0.42a	1.33
DAP	18.82b	0.50a	15.77	5.59	0.96a	1.00
TSP	10.04a	0.99a	15.18	5.03	0.74a	1.13
RP (as avai.P)	7.33a	0.97a	14.28	5.66	0.45a	1.08
RP (as total P)	7.82a	2.49b	18.35	5.86	0.62a	1.10
F-Test	**	**	NS	NS	*	NS
C.V. (%)	33.42	58.32	26.32	44.38	38.07	37.72

Remark: *, ** = Significant difference at $P \leq 0.05$ and ≤ 0.01 respectively.
NS = Not significant at $P > 0.05$.
The letters (a-b) in each column shows significant difference at $P \leq 0.05$.

TABLE 7. EFFECT OF PHOSPHATES FERTILIZERS ON TAP ROOT NUTRIENTS.

Treatment	Tap Root Nutrients					
	N	P	K	Ca	Mg	Mn
	$g\ kg^{-1}$					$mg\ kg^{-1}$
Control	6.66a	0.30	4.96	1.79a	0.35a	0.56a
DAP	13.23b	0.54	6.15	2.35a	0.45ab	0.35bc
TSP	8.60ab	0.70	5.04	2.79a	0.65b	0.23c
RP (as avai.P)	7.75ab	0.46	6.36	3.25a	0.51ab	0.44bc
RP (as total P)	7.24ab	0.97	5.88	6.66b	0.55ab	0.43abc
F-Test	*	NS	NS	**	**	**
C.V. (%)	30.97	53.24	20.05	24.10	18.90	20.81

Remark: *, ** = Significant difference at $P \leq 0.05$ and ≤ 0.01 respectively.
NS = Not significant at $P > 0.05$.
The letters (a-c) in each column shows significant difference at $P \leq 0.05$.

TABLE 8. EFFECT OF PHOSPHATES FERTILIZERS ON LATERAL ROOT NUTRIENTS.

Treatment	Lateral Root Nutrients					
	N	P	K	Ca	Mg	Mn
	$g\ kg^{-1}$					$mg\ kg^{-1}$
Control	23.17a	0.75a	12.46	2.12a	0.67a	1.52a
DAP	29.58a	0.92a	11.99	2.56a	0.87ab	1.36b
TSP	22.80a	1.31b	14.61	2.92a	1.02b	0.97b
RP (as avai.P)	21.08a	0.84a	14.26	3.39a	0.78a	1.30a
RP (as total P)	28.46a	1.35b	16.39	6.49b	0.68a	1.05b
F-Test	*	**	NS	**	**	**
C.V. (%)	15.32	13.68	14.44	21.21	12.44	31.44

Remark: *, ** = Significant difference at $P \leq 0.05$ and ≤ 0.01 respectively.
NS = Not significant at $P > 0.05$.
The letters (a-b) in each column shows significant difference at $P \leq 0.05$.

In spite the addition of P fertilizer tended to decrease Mn concentration in all parts, TSP treatment showed the highest leaf Mn (Table 4) and petiole Mn (Table 5) compared to others and control. On the contrary, both on the tap root (0.23 $mg\ kg^{-1}$) (Table 7) and lateral root (0.97 $mg\ kg^{-1}$) (Table 8), TSP gave significantly ($P \leq 0.01$) impact on the decreasing Mn concentration, which is similar to the lowest stem Mn (1.00 $mg\ kg^{-1}$) due to DAP application.

The pH values of soils where P fertilizer was applied showed markedly lower than control, with DAP treatment as the lowest value (4.89) (Table 9). Meanwhile, RP as total P had markedly ($P \leq 0.01$) impact on the increasing exch. Ca (0.687 $Cmol_c\ kg^{-1}$) and avai. P. (137.81 $mg\ kg^{-1}$). Though, the response of P treatment to the organic matter (OM), electrical conductivity (EC), exch. K, exch Mg and extr. Mn values were not significantly found, it tended to increase and the values were higher than that in the control.

TABLE 9. EFFECT OF PHOSPHATES FERTILIZERS ON SOIL NUTRIENTS.

Treatment / Soil properties	Control	DAP	TSP	RP as avai.P	RP as total P
pH**	5.45a	4.89b	5.18b	5.01bc	5.11b
EC ($ds\ m^{-1}$)	0.090	0.094	0.063	0.088	0.103
Avai.P ($mg\ kg^{-1}$)**	7.32a	26.02a	22.16a	25.27a	137.81b
Extr. Mn ($mg\ kg^{-1}$)	16.07	20.40	17.41	22.42	23.88
OM (%)	6.165	6.505	6.350	6.391	6.644
Exch.K ($cmol_c\ kg^{-1}$)	0.727	0.751	0.528	0.683	0.829
Exch.Ca ($cmol_c kg^{-1}$)**	0.251a	0.245a	0.246a	0.308a	0.687b
Exch.Mg ($cmol_c kg^{-1}$)	0.064	0.065	0.061	0.062	0.067

Remark: ** = Statistically significant difference at $P \leq 0.01$.
The letters (a-c) in each row shows significant difference at $P \leq 0.05$.

IV. DISCUSSION

Effect of P fertilizers on rubber growth

The P requirement for optimal growth is in the range of 0.3 to 0.5 % of plant dry weight [12]. Phosphorus is responsible in the energy storage and transfer[17], the lacking of sufficient P results in the decreasing of respiration and photosynthesis rate [15] which affect to the plant growth. The energy obtained from photosynthesis and metabolism of carbohydrates is stored in phosphate compounds (ADP and ATP) for subsequent use in growth and reproductive process [17]. Adequate P also enhances the nitrogen fixation, flowering, fruiting and maturation of plants [28]. The total dry weight and tap root (Table 1) were significantly highest when the utilization of TSP. It suggests that a good supply of P will improve the developing of root hairs which is expanding root surface area, in result, enhanced the nutrients uptake([5], [17]).

The diameter (Table 2) also showed the significantly increased as long as TSP treatment, because the high solubility of TSP will be highly ready for plant absorption. As result, the rate of plant growth enhances significantly. The usage of RP at the beginning of planting in acid soil also gave the greatest effect of the height and number of leaf (Table 2). Those results also suggest that addition of P fertilizers is able to increase nutrients uptake which is important for plant growth such as potassium, nitrogen, magnesium and calcium (Table 4-8).

The addition of P fertilizers is important for plant growth in acid soils, where P deficient is found ([8], [1], [28]). The P commonly becomes fixed by Al and Fe, resulting in to be unavailable for plant [28]. The deciding of RP usage showed beneficial effect for the long term plant alike rubber, because RP has not acidification effect and the efficiency increases as long as plant growth ([39], [17]). Those results are consistent with earlier findings suggesting that RP was able to increase the growth and yield of rubber in Srilanka [29] and Malaysia [26].

Effect of P fertilizer on chlorophyll

The reaction between P and N is an important in biosynthesis of chlorophyll. The addition of urea at the beginning of planted enhanced the chlorophyll concentration (Table 3). This result was consequential agreement with the experiment of *Chaetomorphalinum* that explained the increasing activity of chlorophyll biosynthesis by synergism of N and P. It also implied that the addition of P without N application did not give significantly effects [25]. Hence, the treatment of DAP gave significantly the highest effect of chlorophyll concentration because DAP contains the greatest N (Table 3). The clearly transport mechanism started with the assimilation of NH_4^+ into amino acids that are subsequently combined into proteins and nucleic acids which provide the framework for chloroplast [17], therefore chloroplast contain up to 75% of N [34]. The consistent result of effect P on elevating chlorophyll was studied in celery [46].

Effect of P fertilizer on plant nutrients

Phosphates ions are involved in major chemical reactions in soils and in numerous metabolic reactions in plants [9]. It is well known that DAP contains 18%N and 20% P (18-46-0) [11], in consequent the N concentration in all plant parts were the highest in the DAP treatment. The addition of urea in the beginning of planting also possible increases the N concentration in plants. The highest N concentration was found in the leaf (Table 4) due to N is the main contributor of chloroplast [34]. The second order was found in the both of root (Table 7 and Table 8), due to root is the most important organ for acquiring soil N, which is able to define the fastest N ion (NO_3^-) absorption to the plant organ [2].

The greater absorption of NH_4^+ or NO_3^- will also rapidly reduce Ca^{2+}, Mg^{2+} and K^+ uptake while, increase the $H_2PO_4^-$ absorption [17]. The effect of RP (as total P) on the concentration of P in plant was significant (Table 4, 5, 6, 7 and 8). The theory led us to consider that addition of urea in the beginning of planted also possible increased the solubility and absorption of P ([9], [11]). The nitrification of N [9] will increase root growth, followed by altering plant metabolism and increasing solubility of P [17]. In other word, the synergistic effect of conjoint placement of N and P fertilizers on root growth resulted on the increasing P uptake by the crop [17].

Plants take up K five to ten times as much as for P [28]. Potassium concentration in plant showed the greatest significant in the RP (as total P) treatment. This finding suggests that K is probably a universal coprecipitant with P when mixed fertilizer containing both K and P are applied at the beginning of planting [9]. The highest K concentration was found in the petiole (Table 5) and stem (Table 6), this result tend to the theory that K able to enhance the strength of stem meristem [28]. The increasing K uptake as addition of P fertilizers is possible because P fertilizer increase the energy. Phosphate is component of ATP required for nutrient uptake [17].

The highest content of Ca in plant on the RP (as total P) treatment is due to RP consists large amount of tricalcium phosphate ($Ca_3(PO_4)_2$) [33].The greatest Ca concentration was found in the leaf (Table 4), because the redistribution of Ca is mainly with the transpiration water in xylem, rather than in phloem [28]. The availability of Ca from RP is essential, because it would be coupled with ADP to produce ATP in plant [9]. Those facts contribute to the restricted movement of Ca to others part [28].

The positive correlation between P and Mg on plant uptake was found in this present study. It appears that Mg concentration in the DAP and TSP treatments was the highest in leaf (Table 4), followed by petiole (Table 5), stem (Table 6), tap root (Table 7) and lateral root (Table 8), because DAP and TSP provide 0.3% Mg in every weight of applied fertilizer [35]. The highest Mg content was found in leaf (Table 4) because Mg is the central component of chlorophyll molecules [28]. Furthermore, the supply of Ca and Mg by mass flow in soils is greater than uptake, thus the accumulation of these nutrients at the tap plant would be expected [12].

According to the results, it was clearly showed that RP has high suitability for better rubber growth and plant nutrients under acid condition. Rock phosphate is able to increase the P concentration and Ca concentration greatly which is important for plant growth in acid soils where P deficient commonly occurred. The slow release of RP becomes necessary to reduce the possibility of fixation between $H_2PO_4^-$ with Fe or Al ions [28]. Rock phosphate also can enhance the concentration of nutrients (N, Mg and K) eventhough, did not as great as DAP or TSP. It also well known that the efficiency of RP will raise as long as the long growing term of rubber [17].

Effect of P fertilizers on Mn concentrations in plant

The reaction between Mn and P is independent of ionic strength [8] but depends on pH which causes the antagonism and synergism relation [3]. The addition of TSP fertilizer in soils affected the increasing Mn concentration in leaf (Table 4) and petiole ($P \le 0.05$) (Table 5). The increasing Mn uptake could be related with the increased vitality, growth and transpiration rate in the well solubility of P treatment [22]. The possibility mechanism is started with the moving of Mn as a cation and coordinated with oxygen donors in plants which will be higher at the high P concentration in solution. As a result, Mn is easily remobilized and makes the accumulation of Mn in plant shoot ([31], [41]). Those results are substantial agreement with the experiment in macadamia [36], sorghum (Sorghum bicolor L.) [24], barley (*Hordeumvulgare* L.) [45], potato [38], wheat ([14], [18]) and *Arabidopsis*[7] which markedly increased Mn shoot concentration during P availability increased [22].

Nevertheless, the effects of P fertilizers on Mn concentrations tended to decrease in all parts of plants, especially on both tap root (Table 7) and lateral root (Table 8) ($P \leq 0.01$) which were markedly lower than that in the control. The experiment on MnSOD demonstrated the possibility mechanism of controlling Mn availability depends on the P anions. It was crucial for understanding that Mn^{2+} posed SOD activity interactions (electrostatic or binding) with $H_2PO_4^-$ / HPO_4^{2-} anions [10]. As a result new form of Mn transport as $MnHPO_4$ was insoluble in plant root vacuoles ([16], [43]). The negative interactions between Mn and P in root were studied in tea [41] and conifer *Pseudotsugamenziesii* [42].

The mechanism of Mn transport by roots plants are started with releasing Mn from solid phase into solution by dissolution or desorption, finally Mn is transported to the root surface by mass flow and diffusion [44]. Manganese generally tends to accumulate predominantly in the plant shoots than in the roots. It is caused Mn transport in the xylem faster and immobile in the phloem [37]. Manganese also has a low electro-negativity which is easily translocated to the tops [43], consequently the Mn toxicity symptom occurs in above ground. The decreasing Mn concentration in every part of plant as well as P fertilizer indicates that application of P fertilizers are able to decrease Mn toxicity and increase the rubber growth under P deficiency where commonly occurs in acid soils.

Effect of P fertilizers on soil nutrients

The effect of high soluble P fertilizer (DAP and TSP) on the decreasing pH (Table 9) and increasing Mn uptake is due to TSP and DAP have an acidifying effect on the soil [11] by dissolved superphosphate or nitrification [9]. This acidification process will affect the increasing Mn content in soils and uptake by plant ([9], [22]). Therefore, leaf Mn (Table 4) and petiole Mn (Table 5) were the highest in TSP treatment.

The increasing of soil and plant nutrients during application of P fertilizer (Table 9) was in essential agreement with the experiment of rubber [47] and celery [46]. The using of RP is great beneficial because the slow release will help to reduce the unavailable process (P fixation) [5] and RP may be longer lasting than those soluble P fertilizer, especially on Oxisols and Ultisols where soluble fertilizer is largely converted to aluminum and iron phosphates [30] within 2 years [11]. The greatest enhancing of P concentrations in soil was also positive correlate with the greater quantity of applying the fertilizer (RP as total P), because RP must be applied three to five times quantities greater than water soluble P fertilizers to make it equivalent [39]. The addition of urea at beginning of planting also give contribution to the greater P uptake by plants by increasing root growth, altering plant metabolism and increasing P solubility and availability [17]. Therefore, the highest P concentration in plants was on RP (as total P) treatment.

The using of RP (as total) also gives beneficial effect in acid condition, because the effectiveness of RP increases as long as the period of growing [17] and it contained the highest Ca concentrations which causes a marked increase in P uptake [9]. In other word, the plant availability of P in RP is directly related to the carbonate content of the apatite ([11], [40]).The presence of Mg in soil exchange sites could also contribute to the releasing Ca from RP [40].

The addition of P fertilizer not only can enhance the plant growth but also can decrease the quantity of trace element in soils by dissolving to form insoluble hydroxyl phosphate precipitates as this equation [28]:

$$Mn^{2+} + H_2PO_4^- + 2\ H_2O \leftrightarrow 2H^+ + Mn(OH)_2H_2PO_4$$

Phosphate fertilizer is able to improve plant growth by many ways such as increasing nutrient uptake and decreasing Mn uptake.

V. Conclusion

The P fertilizer application is able to increase plant growth significantly. The addition of P fertilizer also decreased the Mn concentration in all plant parts. The RP treatment has the lowest Mn concentrations. Otherwise, Mn in leaf and petiole also tended to decrease but on TSP treatment showed the highest Mn concentration. Overall, RP promotes rubber growth and decreases Mn uptake.

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